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# SPACE COMMUNICATIONS PROTOCOL STANDARDS PERFORMANCE TESTING

Richard N. Smith, David J. Legare, and Peter J. Radesi

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FOR THE DIRECTOR:

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Richard N. Smith, David J. Legare, and Peter J. Radesi

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**13. ABSTRACT** *(Maximum 200 words)*

Two computer LAN's, linked by the ACTS satellite, were configured. SCPS-TP and SCPS-NP protocol software was installed on the LAN's. The protocols were tested using various BER's and data rates. This report documents the test results.

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## 1.0 Introduction/Background

Space Communications Protocol Standards (**SCPS**) is a joint DOD (SMC/AXE Maj. Cole, SMC/ADC Lt. Capizzi), NASA (Adrian Hooke, JPL) and NSA (Capt. Vasko) program. The DOD portion of this effort was originally managed by USSPACECOM/J4P. Responsibility for the DOD portion was transferred to the **S**pace and **M**issile System **C**enter (**SMC**) during the latter part of FY96.

The MITRE Corp. functioned as system engineer providing software integration, protocol development, test plans, procedures and reports, and user interface. The software developers included MITRE (SCPS-TP and SCPS-NP), SAIC (SCPS-FP) and SPARTA (SCPS-SP). Validation was handled by the **J**oint **I**nteroperability **T**est **C**enter (**JITC**).

The focus of SCPS is to develop, test and validate four upper layer computer network protocols. The application layer SCPS-**FP** (**F**ile **P**rotocol), transport layer SCPS-**TP** (**T**ransport **P**rotocol), layer 3.5 SCPS-**SP** (**S**ecurity **P**rotocol) and network layer SCPS-**NP** (**N**etwork **P**rotocol) were developed under this joint effort.

Historically, data transmission protocols have been developed with fixed ground application in mind (Example: TCP, IP, and FTP). Space applications exists in a different operational environment relative to fixed ground application. Factors that make the space environment different are constrained bandwidth, higher **B**it **E**rror **R**ate (**BER**), dynamic links, higher link delay and limited computing power onboard the space vehicle. The SCPS protocol suite was developed to better couple the data transmission protocols to the space environment.

This report will cover AFRL/IFGC support for SCPS-FTP, SCPS-TP and SCPS-NP testing for the period 05/97 – 10/97. As system engineer MITRE made the decision to utilize the extensive networking and satellite communication facilities and expertise resident at AFRL/IFGC. Prior to testing at AFRL, SCPS was tested using a lab simulation test bed. Other SCPS tests include the M22 bent-pipe flight test (12/95) and STRV TT&C flight tests during the period (01/96 – 04/96).

## 2.0 What is SCPS?

The Space Communications Protocol Standards is a collection of four integrated, layered protocols which are designed to operate over existing space **T**elemetry, **T**elecommand **&** **C**ommunication (**TT&C**) channels. The standard **C**onsultative **C**ommittee for **S**pace **D**ata **S**ystems (**CCSDS**) and the Link layer or **S**pace **G**round **L**ink **S**ystems (**SGLS**) are examples of TT&C channels. These channels are specified in a set of CCSDS recommendations.

The File Protocol (SCPS-FP) operates at the highest layer (Application Layer 7) in the International Standards **O**rganization (**ISO**) **O**pen **S**ystems **I**nterconnection (**OSI**) reference model. The SCPS-FP is a "tuned up" version of the Internet **F**ile **T**ransfer **P**rotocol (**FTP**). SCPS has been optimized to operate more efficiently in space. SCPS provides certain new services that are required by space missions (such as the ability to manipulate individual records without reloading the whole file).

The SCPS-FP is interoperable with commercial FTP. The "Non-interactive File Transfer Protocol" (SCPS-NiFTP) is a variant of the SCPS-FP that is also under development. This new

protocol is not FTP-interoperable but can tolerate long propagation delays without the need for time-consuming handshaking between space and ground nodes.

Transport Protocol (SCPS-TP) is a modified version of the Internet **T**ransmission **C**ontrol **P**rotocol (**TCP**) and the **U**ser **D**atagram **P**rotocol (**UDP**) operating at the Transport Layer (OSI Layer 4). TCP/UDP generally does not perform well in stressed environments typical of space missions (i.e., networks with high link error rates not simply related to congestion, asymmetry or imbalance between forward and return channel capacities, long propagation delays and interrupted connectivity). SCPS-TP provides reliable end-to-end delivery of spacecraft command and telemetry data over a network containing one or more unreliable space-ground communication channels.

It also includes a mixture of extensions to current TCP features. TP provides window scaling to handle long delays and high volumes of in-transit data, selective acknowledgment and header compression, and "best effort" service that continues to deliver data even if the acknowledgment channel becomes temporarily unreliable. Its implementation has been customized to minimize communications overhead and to fit into resource-limited space systems. A non-interactive variant of the SCPS-TP is currently being considered for very long propagation delay environments where an acknowledgment path effectively does not exist.

The Security Protocol (SCPS-SP) is an optional data protection mechanism which provides selectable levels of end-to-end security (e.g., message authentication, access control, integrity and encryption) and is slotted between the Transport and Network layers (OSI Layer 3.5).

Network Protocol (SCPS-NP) at the Network layer (OSI Layer 3) provides functionality similar to the **I**nternet **P**rotocol (**IP**). IP has been customized to support unique routing configurations. SCPS-NP has been "shrunk down" for space networking applications and provides for flood routing through constellations of spacecraft, which are characterized by fewer nodes relative to global networks. This is to minimize overall communications overhead.

The SCPS-NP can operate in a connection-oriented (circuit-switched) mode similar to the current CCSDS "Path" service, or it can support connectionless (packet-switched) IP-like routing. It is a fully scaleable protocol, whose features (and therefore overhead) are selectable to match the application. Address sizes can range from no address all the way to IP Version 6.

In general, Internet protocols such as TCP/IP (including FTP and UDP) are designed to maximize performance and economy for terrestrial networks. Their approach to retransmission, recovery and time-outs is inappropriate for space applications. Current CCSDS Packet Telemetry, Telecommand and **A**dvance **O**rbiting **S**ystems (**AOS**) protocols, while an improvement over TCP/IP for space applications, focus primarily on basic data transfer. The SCPS protocols extend this capability to more sophisticated space-specific needs such as the ability to combine command and telemetry data into recognizable files and transport them across the space-ground data network with end-to-end reliability and security.

The design of the SCPS suite of protocols is driven by several characteristics of modern-day space missions. Modern satellites provide enhanced onboard processing. The need to communicate critical data reliably is always a consideration, even in the face of link failures. The need to efficiently trade off buffer use, reliability and message delay is critical. To automate control and reduce ground support infrastructure is highly desired.

The SCPS protocols may operate as an integrated (OSI Layers 3-7) stack or be

individually selected to match a particular application (e.g., running the File Protocol directly over an inherently reliable link layer such as CCSDS). In general, they have been designed for an environment in which one end of a data transfer is on the ground and the other end is hosted in a satellite onboard processor with relatively constrained CPU and memory capabilities and where communication bandwidth is at a premium. The code implementations are therefore deliberately "skinny" (i.e., sparse or spare) and operate with high data transfer efficiency. Though designed initially for traditional spacecraft telemetry and telecommand applications, many of the protocol features have the potential for useful commercial application, including high rate data transfer through noisy, long delay satellite channels.

In conclusion, SCPS was developed for space applications which, as such, exist in a different operational environment relative to fixed ground applications. In a space environment constrained bandwidth, higher BER, dynamic links, higher link delay and limited computing power onboard space vehicles require a more robust protocol suite such as SCPS. SCPS is also applicable to tactical, ground mobile and ground/air environments. SCPS provides considerable improvement over TCP, IP and FTP for all these environments. The SCPS-TP window scaling option addresses large delays. The Negative **ACK**nowledgement (**NACK**) option, and "The best effort transport service" reduced processing overhead and utilize bandwidth efficiently while improving BER performance. SCPS header compression reduces packet overhead and better utilizes bandwidth. SCPS is also responsive to link corruption and /or outage, not just traffic congestion. SCPS NP relative to IP supports connection oriented addressing. This is advantageous for fixed configurations such as GEO satellites. SCPS-IP allows various routing algorithms such as flood, dual-path and others. SCPS-IP also supports packed precedence important in DOD applications. SCPS-FP gets file size prior to transfer to determine if full file can be transmitted. This is more efficient for dynamic short duration links. SCPS-FP supports update of individual records thus making better use of bandwidth and improving efficiency. Automatic restarts for file transfer supports link reconfigurations such as LEO contacts. SCPS-FP supports file/record error checks for true E/E error detection. These factors make SCPS a standardized solution, for space applications, which provides improved performance relative to fixed ground based data transmission protocols.

## 3.0 Test Configurations

Two distinct test configurations were required to complete the SCPS test plan. Test configuration 1 supports SCPS-TP and FP testing while test configuration 2 supports SCPS-NP testing. All testing was conducted over the NASA Advanced Communications Technology Satellite (ACTS). The ACTS satellite at present is a one-of-a-kind resource in that it operates in the Ka band of the RF spectrum. This band utilizes the 29-30 GHz frequency on the uplink and 19-20 GHz on the downlink. The Ka band is much higher in frequency than the present commercial bands such as the C, X, and Ku bands. This makes it more susceptible to atmospheric conditions such as clouds and rain. It thus provided for a more rigorous testing of the SCPS protocols in that they had to compensate for a wider variation in channel parameters, and bit error rates and patterns than would have been present if the testing had been conducted over leased commercial or DOD satellite channels. The Rome Research Site (AFRL/IFGC) was chosen as the SCPS test-bed location because of the existence of an ACTS ground terminal

shelter at the site and Rome's ability to obtain sole user status on the ACTS satellite for the extended time periods required for the SCPS testing. This allowed for unlimited flexibility in terms of channel bandwidth and separation, and the ability to completely control transmitted power so that bit error rates (based on Eb/No) could be adjusted and maintained at desired levels for any given test segment. This control was absolutely necessary to evaluate protocol performance under different channel conditions. The test configuration at Rome also allowed for the provision of a full duplex link while keeping the entire test-bed within a single location. The test was therefore functionally identical to having two LANs separated by a geographic distance as great as could be covered by the footprint of a given satellite (i.e. 100 to 1000 miles). This was accomplished by configuring the two modem and router sets (for LANs 1 and 2) to operate through a single RF up and down conversion stage (and a single 1.8 meter satellite dish) while transmitting on two widely-spaced IF frequencies out of the modems. Each of the LANs was connected via its own fiber optic cable pair (from inside the AFRL Network Communications Lab in Bldg. 3) to the modems which were collocated with the satellite terminal near the South side of the building.

## 3.1 Test Configuration 1

Unique to SCPS-TP and SCPS-FP testing is test configuration 1 shown in Figure 1 which was established at AFRL/IFG specifically for the testing activity. Configuration 1 provides connectivity between LAN-1 and LAN-2 via the ACTS satellite. Only one Ka band satellite terminal is required because its bandwidth is wide enough to provide a dual full duplex capability.

The workstations, labeled WS1, WS3 and WS4, are IBM PC clones employing the FreeBSD 2.1.6 operating system. These workstations make up LAN-1, the source side of the link. Each workstation supports two Ethernet cards which provide connectivity to LAN-1 and the **R**ome **L**aboratory **C**omputer **N**etwork (**RLCN**) Ethernet. This allows isolation for LAN-1 and at the same time remote access to control test functions. Remote control of modem function is provided via the RS-232 interface of the router, which is attached to LAN-1. This allows the transmitted power on the satellite uplink to be controlled from a terminal on the LAN. This transmitted power is adjusted to set the bit error rate (BER) for any given protocol test. After changing transmit power the link error rate is verified by running the bit error rate tester (BERT) function built into the modems prior to each new protocol test period. The Transmit/Receive data path between the modem and the router is provided via the router RS-449 interface. This provides for the flow of data between LAN-1 and LAN-2 via the satellite link. Workstation WS1 hosts TCP/IP, SCPS-TP/IP, SCPS-FP/SCPS-TP/IP and test drivers. Workstation WS3 is the congestion traffic generator. Workstation WS4 is the LAN-1 traffic monitor.

LAN-2, the destination, is configured identical to LAN-1 except that LAN-2 employs only one FreeBSD workstation WS2. WS2 hosts TCP/IP, SCPS-TP/IP, SCPS-FP/SCPS-TP/IP and test drivers. The satellite link data can flow freely between LAN-1 and LAN-2 all under remote control via WS7 the test controller. WS7 is configured similar to the other workstation and provides access to both LAN's via the RLCN Ethernet.

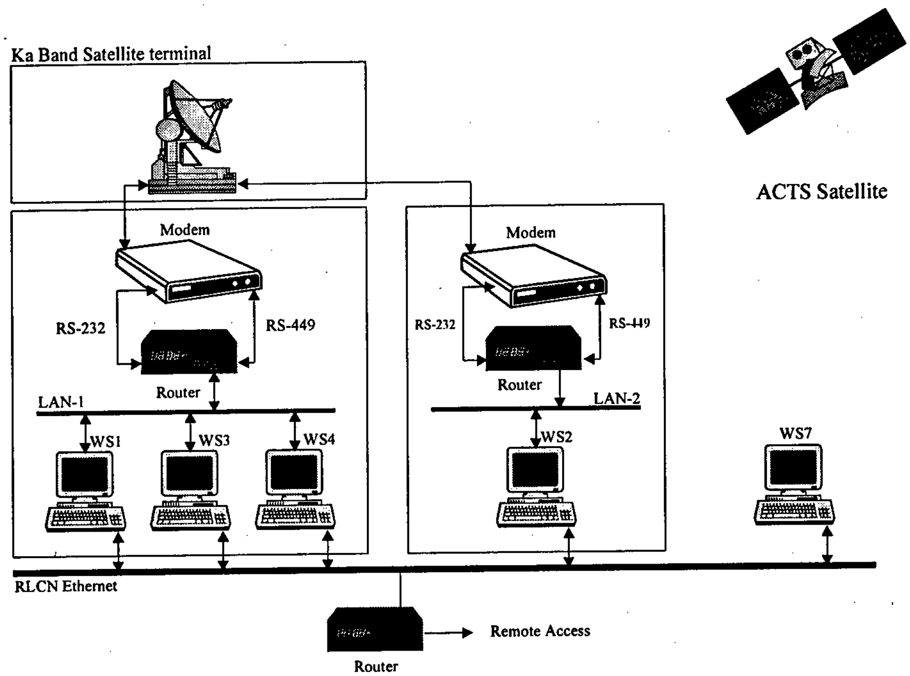


**Figure 1. Test Configuration 1**

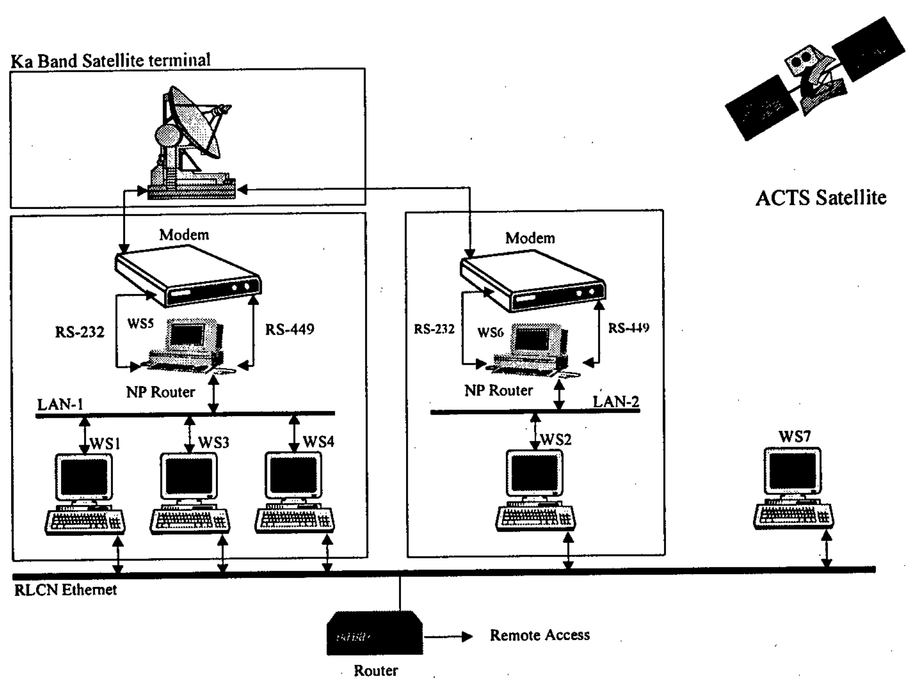


**Figure 2. Test Configuration 2**

## 3.2 Test Configuration 2

Test configuration 2, as shown in Figure 2, is unique to SCPS-NP testing. This configuration is similar to test configuration 1, and thus only the differences will be described here.

For both LAN-1 and LAN-2 the routers that provide the data and control functions between the LAN's and the modems are replaced with IBM PC clones (WS5 and WS6) running the FreeBSD operating system. The workstations WS5 and WS6 are configured to be SCPS-NP routers. RS-449 interface cards were inserted in the workstations so their hardware functionality is identical to the routers in test configuration 1. This setup can provide SCPS-TP/SCPS-NP over the satellite link. Over the LAN's SCPS-TP/SCPS-NP encapsulated in IP is used.

## 4.0 Test Procedures

The focus of SCPS testing was to define the performance of SCPS-TP in terms of comparison to the current standard (TCP). A number of parameters effect the performance of SCPS-TP relative to standard TCP. Factors considered are size of the file being transferred, packet size, buffer size, network congestion and communications link corruption. All these factors come into play when we consider networks containing wireless communication links. Wireless networks are subject to bandwidth constraints, and periods of poor BER performance and outages.

## 4.1 Congestion and Corruption

TCP was designed to interpret lost packets as a sign of congestion on the network. While this is a good assumption for terrestrial networks, it is not appropriate for networks depending on wireless communication links. Networks depending on wireless communications can be degraded by poor signal to noise ratio leading to poor BER performance. This is not usually the case with terrestrial networks. We refer to a degraded communication link as being corrupted as opposed to a terrestrial network that becomes congested. In both cases the result is lost packets. It is clear that the best way to deal with lost packets is dependent on whether the network is congested or corrupted. SCPS-TP is capable of detecting corruption and responding appropriately. This means that SCPS-TP will out perform standard TCP in networks containing corrupted communication links.

## 4.2 Satellite Link Delay

If a network contains satellite communications links then long link delays will result. This delay is noticeable for all types of long distance links, but is particularly evident with geosynchronous satellites (such as ACTS) where the link distance is on the order of 50,000 miles with a corresponding transmission delay of 250 milliseconds per satellite hop. TCP suffers severe performance loss in the presence of such delays. SCPS-TP was designed to handle the long delays and respond appropriately. The size of the file being transferred, packet size and

buffer size were varied during the test to accentuate the ability of SCPS-TP to deal with long link delays.

## 5.0 Test Results

The SCPS protocol suite was tested under both a corrupted and/or a congested link environment. A corrupted link is when the BER on the channel is high (one error in a million or worse). A congested link results in degraded performance due to a large number of users and/or heavy traffic over the link. Other parameters that effect SCPS performance, such as data rate over the link, size of the file being transferred and packet size, were also evaluated.

## 5.1 Corrupted Link

Figure 3 shows the performance of TP, with and without congestion control, as compared to standard TCP. The improvement of TP over standard TCP is quite remarkable for links with a BER greater than one in a million. The data shows that even with congestion control turned on, TP still out performs TCP in a corrupted link environment. As the chart shows, this data was collected using a 4MByte file, 1400 byte packets and 200 Kbytes buffers.

Figure 4 is essentially the same as figure 3 except packet size is 512 bytes. At this packet size we can see that TP performance, even with congestion control turned on, is impressively out performing TCP even at good link BER. In Figure 5 the packet size is 50 bytes and the file size is 0.5 Mbytes. At these packet sizes TP is only using a quarter of the available bandwidth as compared to TCP only using a tenth of the link capacity. With congestion control turned on, TP is only slightly better that TCP at low BER. With or without congestion control, TP still outperforms TCP.

## 5.2 Congested Link

When congestion control is enabled SCPS-TP applies the TCP Vegas congestion control algorithms to minimize loss and facilitate the use of large windows. In Figure 6, the data was collected under congested link conditions with congestion control on, 2 MBPS link capacity, and a 4Mb file with 1400 byte packets. Because both TP and TCP use the same congestion algorithm, we expect performance to be similar as evidenced by Figure 6.

Figure 7 is essentially the same except a packet size of 512 bytes is used. Again because TP and TCP use the same congestion control scheme the data, as expected, shows similar performance.

In Figure 8 the data was collected under congested link conditions with congestion control on, 2 MBPS link capacity, and a 0.5 Mb file with 50 byte packets. Because both TP and TCP use the same congestion algorithm, we expect performance to be similar as evidenced by Figure 8.

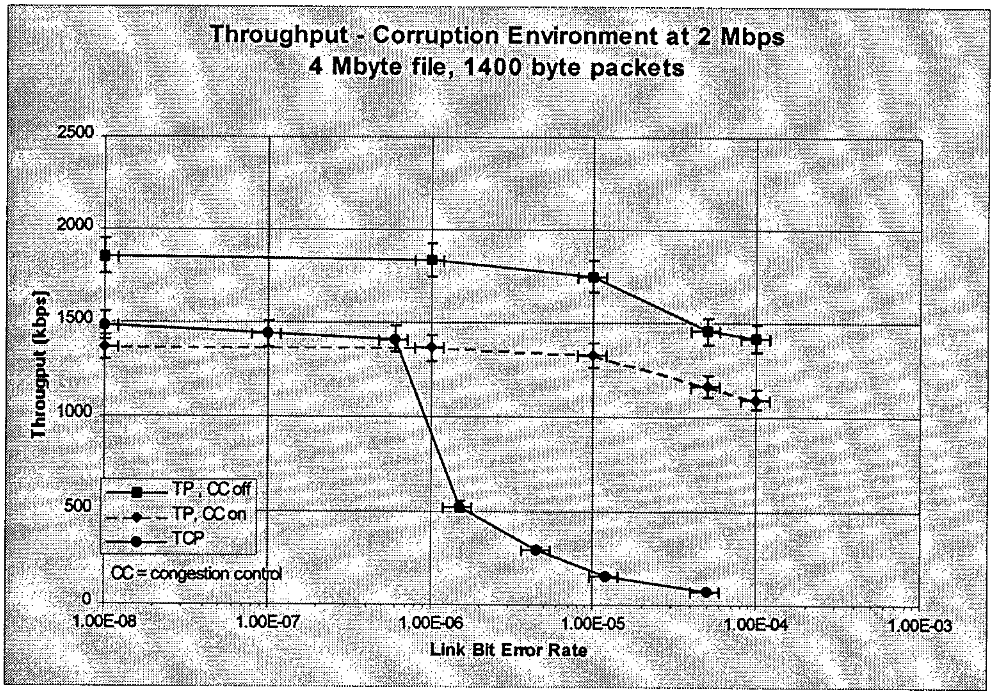


Figure 3

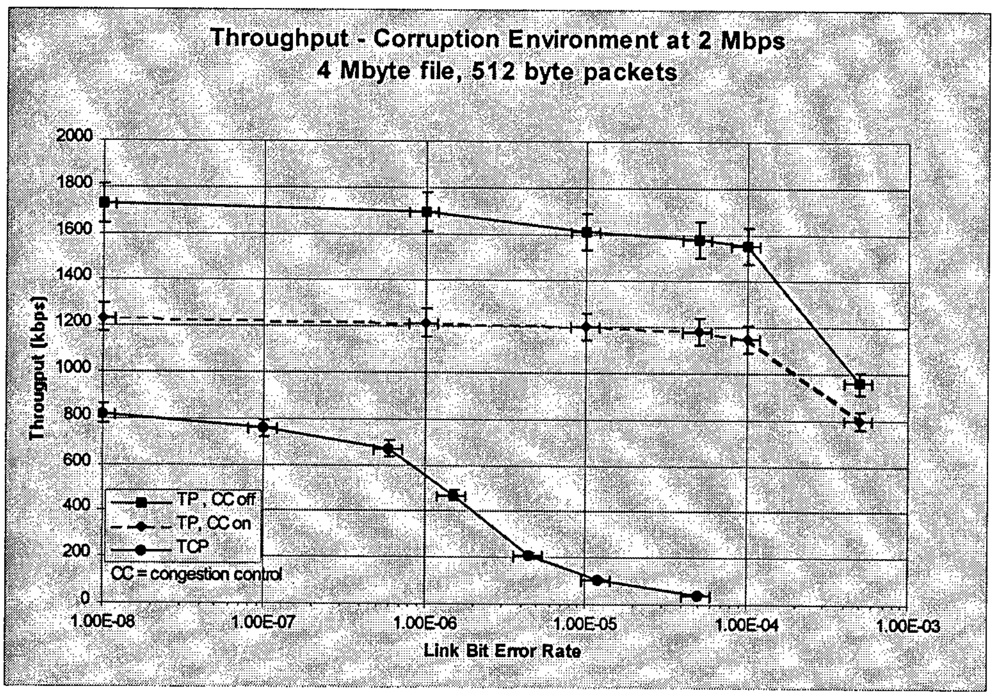


Figure 4

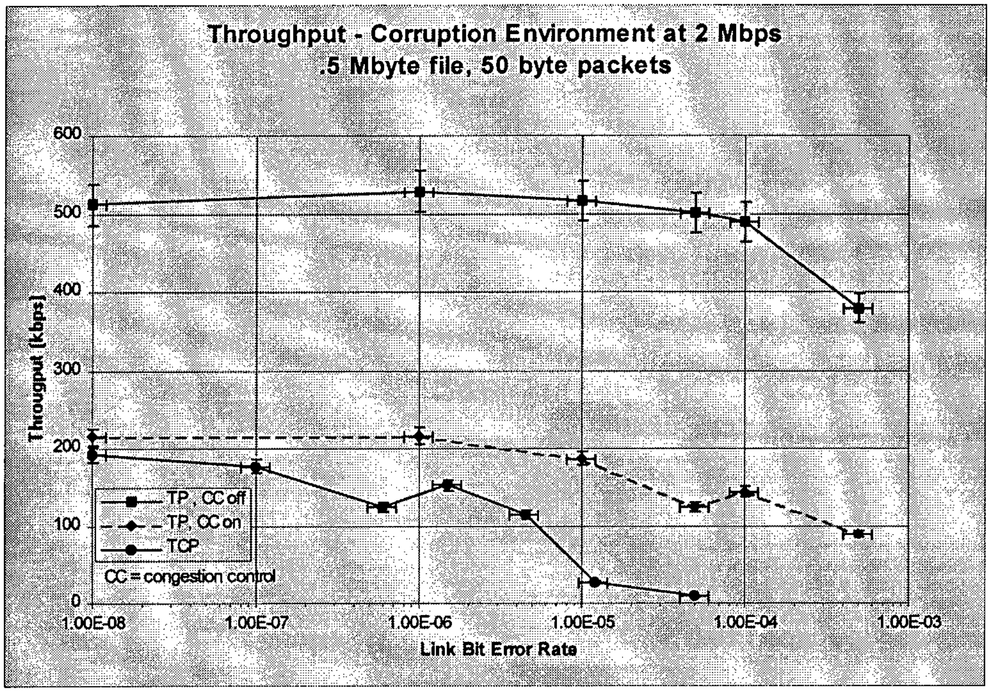


Figure 5

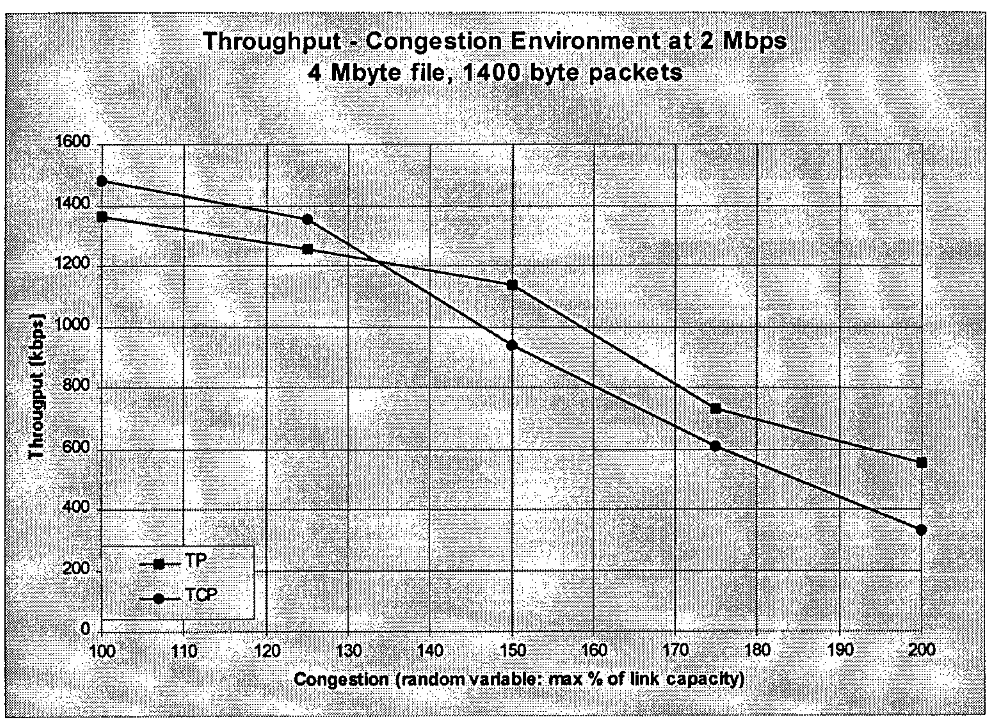


Figure 6

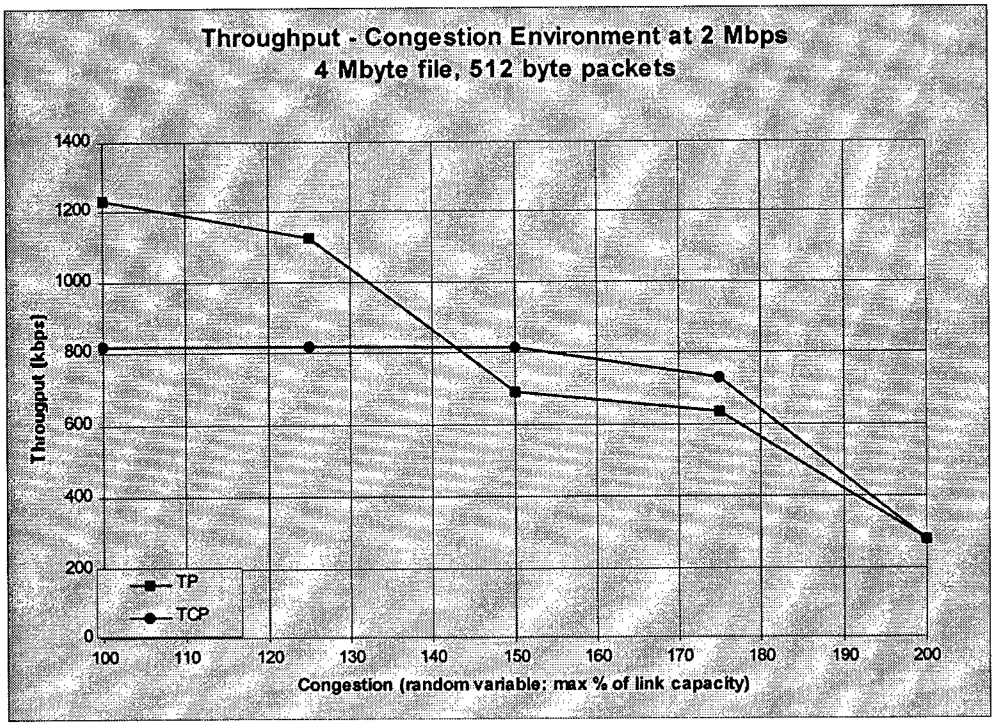


Figure 7

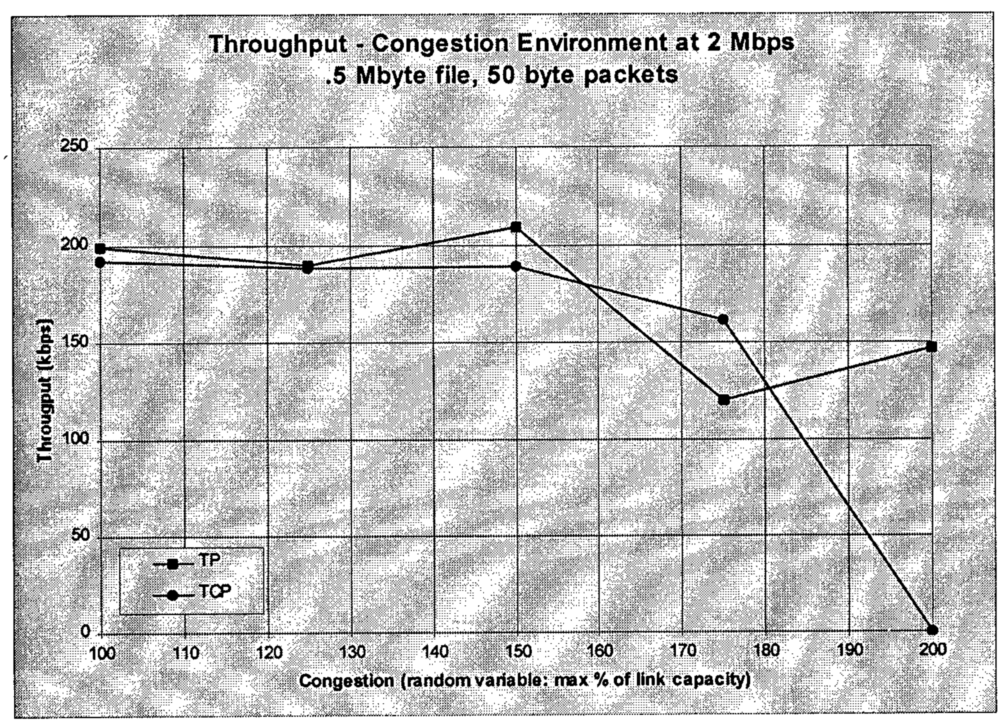


Figure 8

## 6.0 Conclusions and Recommendations

The space communication environment differs from the terrestrial (wired) communication environment in ways that significantly effect transport protocol performance and the quality of service to the user. While TCP works well in the terrestrial environment, modification is necessary to provide good performance in the satellite environment. One of the primary differences between space communication environments and current terrestrial environments is the source of data loss. Terrestrial networks primarily experience loss caused by congestion. In contrast, space communication networks exhibit mixed loss characteristics. Losses can result from congestion, corruption, or link outages.

TCP's assumption that virtually all loss is caused by congestion results in severe degradation of performance in error-prone wireless environments. When losses are not caused by congestion, SCPS-TP's throughput remains high by avoiding the congestion-control response and by providing enhanced information about data loss via the SCPS-TP Selective Negative Acknowledgment (**SNACK**) option.

The test program has shown that SCPS provides greatly improved performance in a wireless environment while maintaining performance at least as good as TCP in a terrestrial (wired) environment. It is recommended that the SCPS protocol development be completed and software versions made available for all major computer platforms to support both commercial and military users.

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